# Little hierarchy in the minimally specified MSSM

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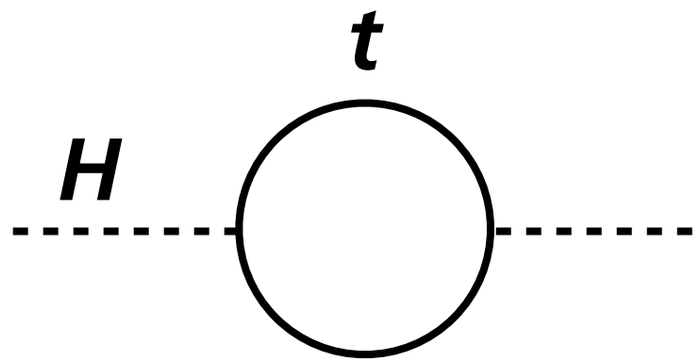
# Fine tuning problem in EWSB

in a bottom up approach is seen as the cancellation of two numbers:

**the top loop contribution to the Higgs mass squared**




$$\Delta m_H^2 = -\frac{\lambda_t^2}{8\pi^2}\Lambda^2 + \dots$$

**and the boundary condition at the scale of new physics.**

# Quantifying fine tuning

In a model with two parameters A, B ~ 1 contributing to X,

$$X = A - B$$

in order to get e.g. X = 0.001, parameters A and B have to be specified with 3 digits and carefully chosen/tuned

e.g.: A = 0.963
B = 0.962

## Tuning often quantified by:

$$\max_{p=\{A,B\}} \left| \frac{\partial \ln X}{\partial \ln p} \right| \simeq \frac{A}{X} \simeq 1000$$

**0.1% tuning**

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**0.1% tuning**

**Note that ~10% tuning corresponds to specifying A and B with one digit: no matter what the remaining digits are, we need to adjust just the first digit of model parameters to get X ~ 0.1**

# Fine tuning in the MSSM

In the MSSM there are several parameters contributing to the electroweak scale, e.g:

$$M_Z^2 \simeq -1.9\mu^2 + 5.9M_3^2 - 1.2m_{H_u}^2 + 1.5m_{\tilde{t}}^2 - 0.8A_tM_3 + 0.2A_t^2 + \dots$$

boundary conditions at the GUT scale

$\tan\beta = 10$

The usual naturalness measure,

$$\max_p \left| \frac{\partial \ln M_Z^2}{\partial \ln p} \right|$$

only cares about the largest individual contribution. It doesn't tell us how the model parameters need to be tuned/specified.

# Little hierarchy from complexity

e.g. in a model with more parameters contributing to X:

$$X = A - B - c - d$$

in order to get X = 0.001 for randomly chosen A ~ 1, no parameter needs to be carefully chosen, e.g.:

A = 0.963

B = 0.9
c = 0.06
d = 0.002

**only the first digit of all parameters need to be adjusted no matter what the following digits are**

**what is a tuned outcome in a model with 2 parameters may be a completely ordinary outcome in a more complex model**

RD, arXiv:1611.03188

# Outline

Naturalness criteria based on the largest contribution are too strong and do not necessarily indicate how model parameters have to be tuned.

**Naturalness requirement (in this talk):**

**Natural outcome for an observable in a given model is any outcome that does not require specifying more than one digit of model parameters, regardless of what the remaining digits are.**

**Let's see what it means for the CMSSM.**

# Minimally specified CMSSM

Assume model parameters of the same order

$$\mathbf{M_{1/2},\ m_0,\ \mu,\ -A_0\ \simeq\ M_{SUSY}}$$

and vary them in ± 50% range keeping only one digit specifying the departure from $\mathbf{M_{SUSY}}$, e.g.:

$$\begin{aligned}\mathbf{M_{1/2}} &= \mathbf{0.6\,M_{SUSY}}\\ \mathbf{m_0} &= \mathbf{1.1\,M_{SUSY}}\\ \mu &= \mathbf{1.4\,M_{SUSY}}\\ \mathbf{-A_0} &= \mathbf{0.9\,M_{SUSY}}\\ &\vdots\end{aligned}$$

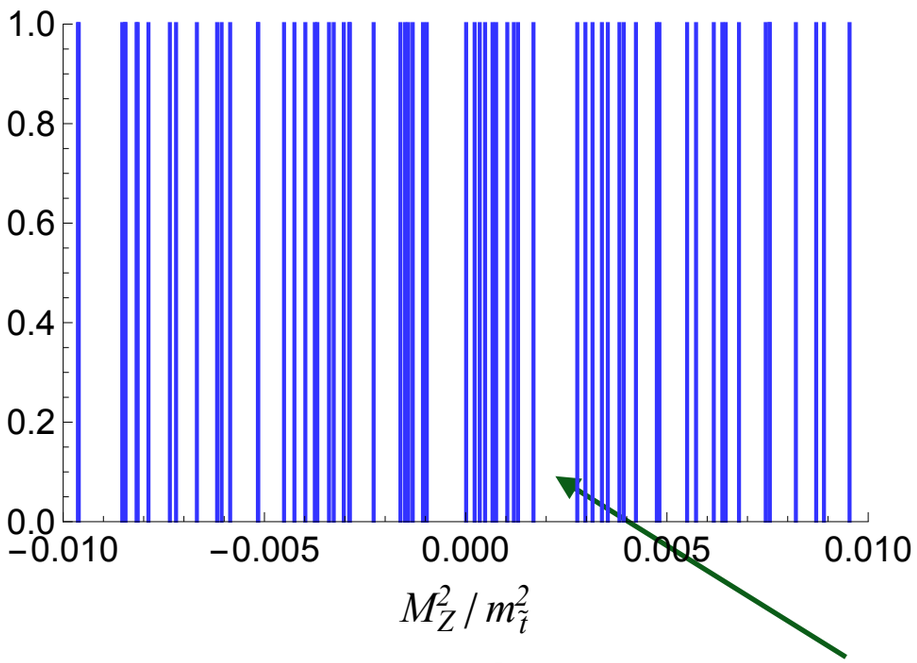
$$\begin{aligned}\mathbf{M_{1/2}} &= \mathbf{0.9\,M_{SUSY}}\\ \mathbf{m_0} &= \mathbf{1.2\,M_{SUSY}}\\ \mu &= \mathbf{0.6\,M_{SUSY}}\\ \mathbf{-A_0} &= \mathbf{0.8\,M_{SUSY}}\\ &\vdots\end{aligned}$$

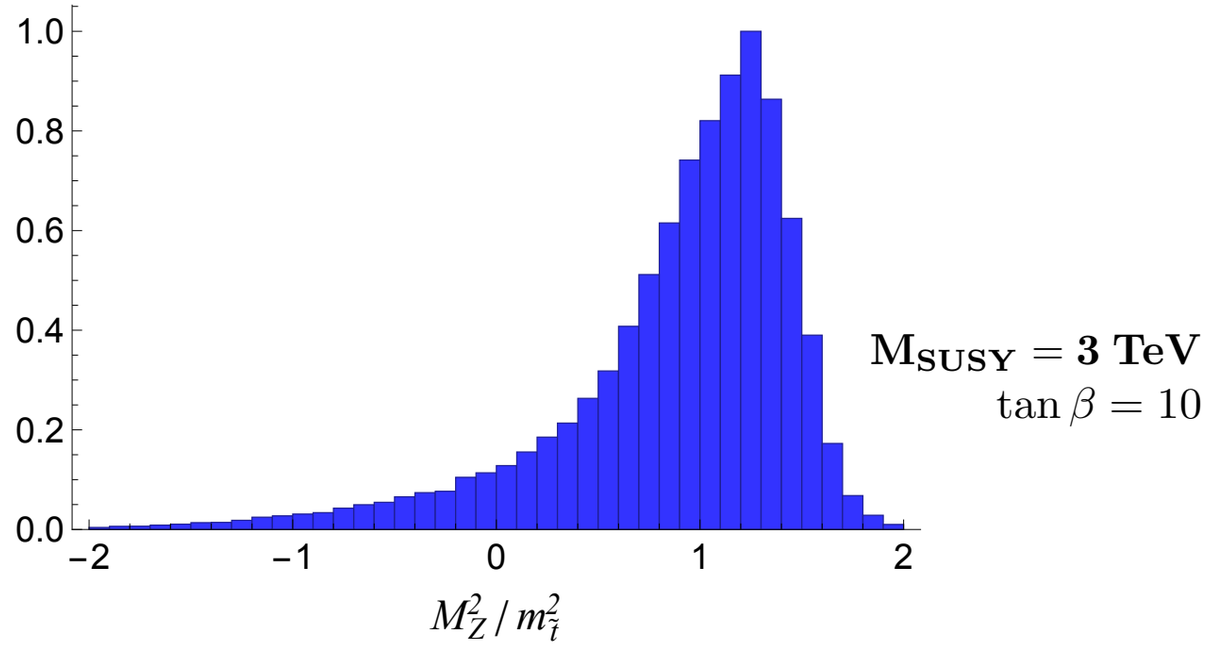
$$\begin{aligned}\mathbf{M_{1/2}} &= \mathbf{0.5\,M_{SUSY}}\\ \mathbf{m_0} &= \mathbf{1.1\,M_{SUSY}}\\ \mu &= \mathbf{1.5\,M_{SUSY}}\\ \mathbf{-A_0} &= \mathbf{0.8\,M_{SUSY}}\\ &\vdots\end{aligned}$$

# Minimally specified CMSSM

## Maximal hierarchy from minimally specified inputs:

**RD and N. McGinnis, arXiv:1705.01910**




**the largest gaps ~0.001 (fairly uniform away from edges of the distribution)**

**The smallest outcome that does not depend on specifying parameters with more than 1 digit is indicated by the largest gap found in the distribution. Outcomes smaller than the largest gap are accidental.**

# Minimally specified CMSSM

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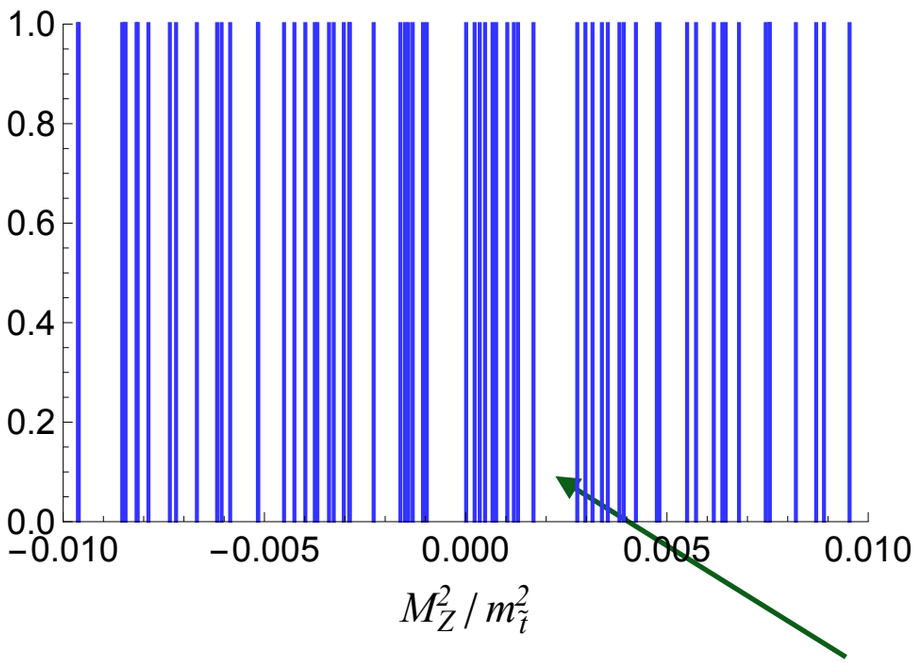
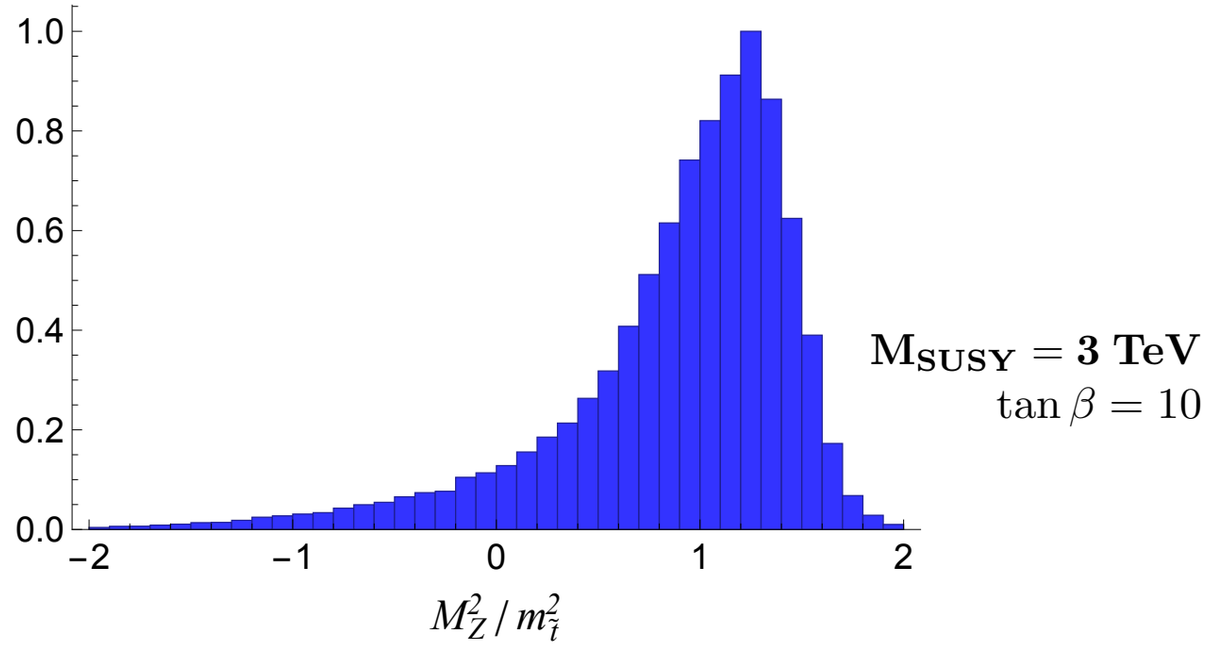



**the largest gaps ~0.001 (fairly uniform away from edges of the distribution)**

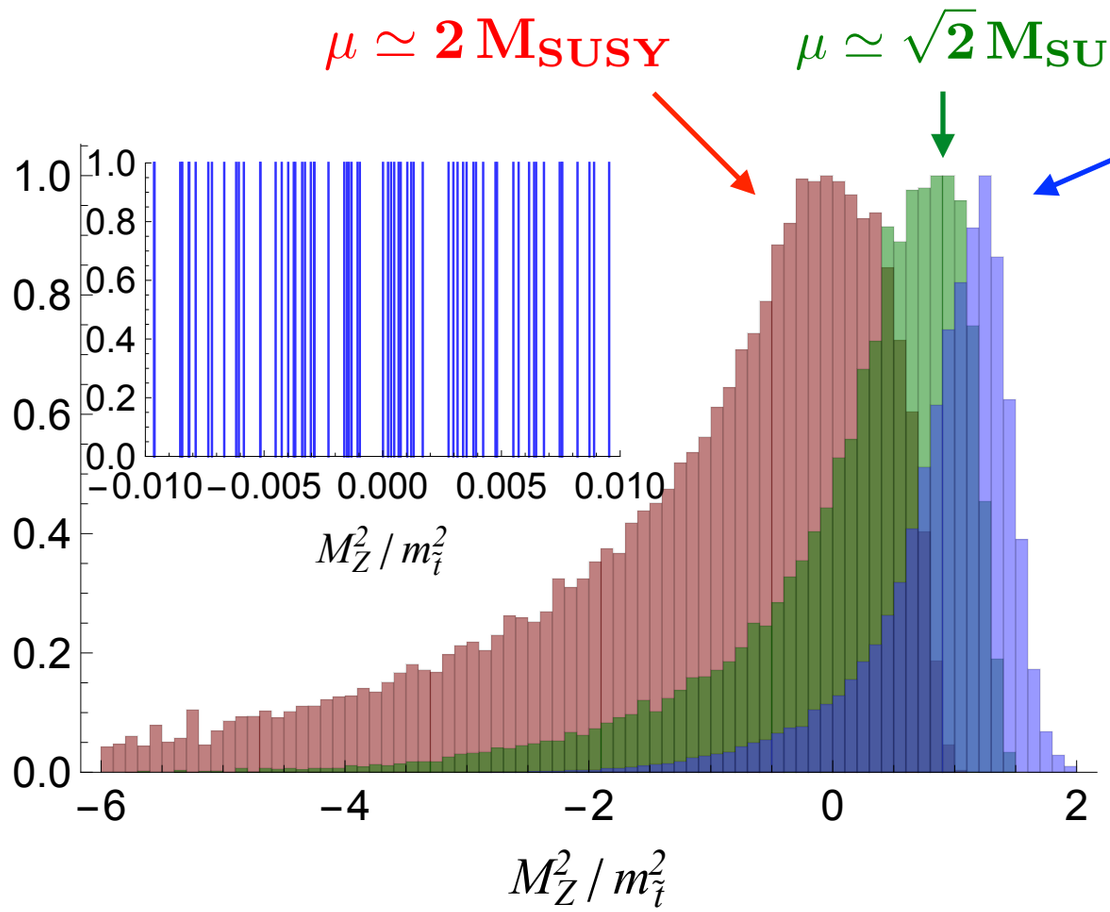
**The smallest outcome that does not depend on specifying parameters with more than 1 digit is indicated by the largest gap found in the distribution. Outcomes smaller than the largest gap are accidental.**

$$m_{\tilde{t}} \simeq 30\, M_Z$$

**is an ordinary outcome from minimally specified parameters**

# Minimally specified CMSSM

For different central values of parameters, the peak of the distribution changes




$\mathbf{M_{1/2} \simeq m_0 \simeq -A_0 \simeq M_{SUSY}}$

$\mathbf{M_{SUSY} = 3\ TeV}$

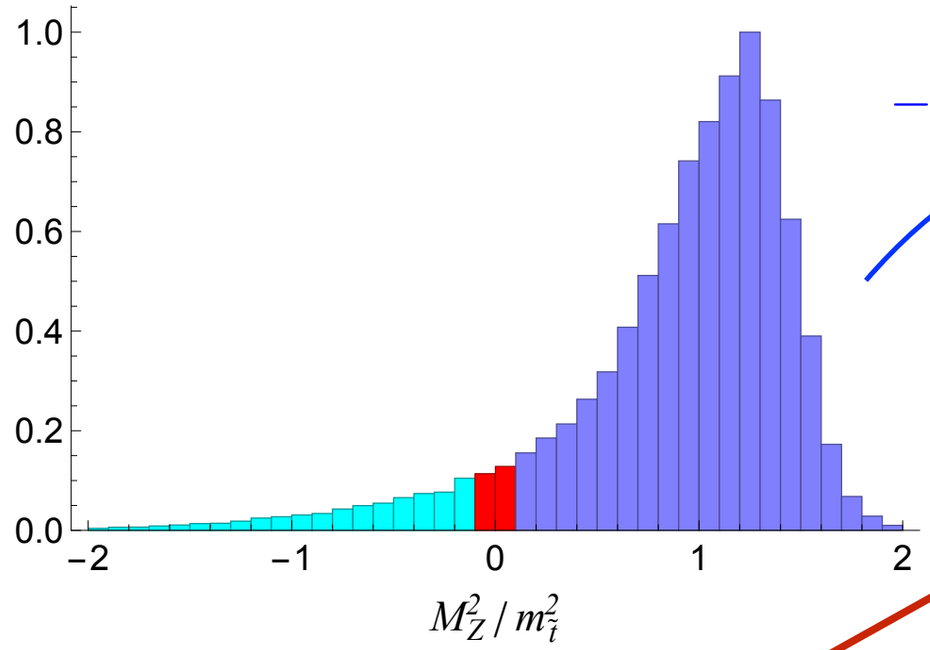
$\tan\beta = 10$

but the maximal gap size remains almost the same.

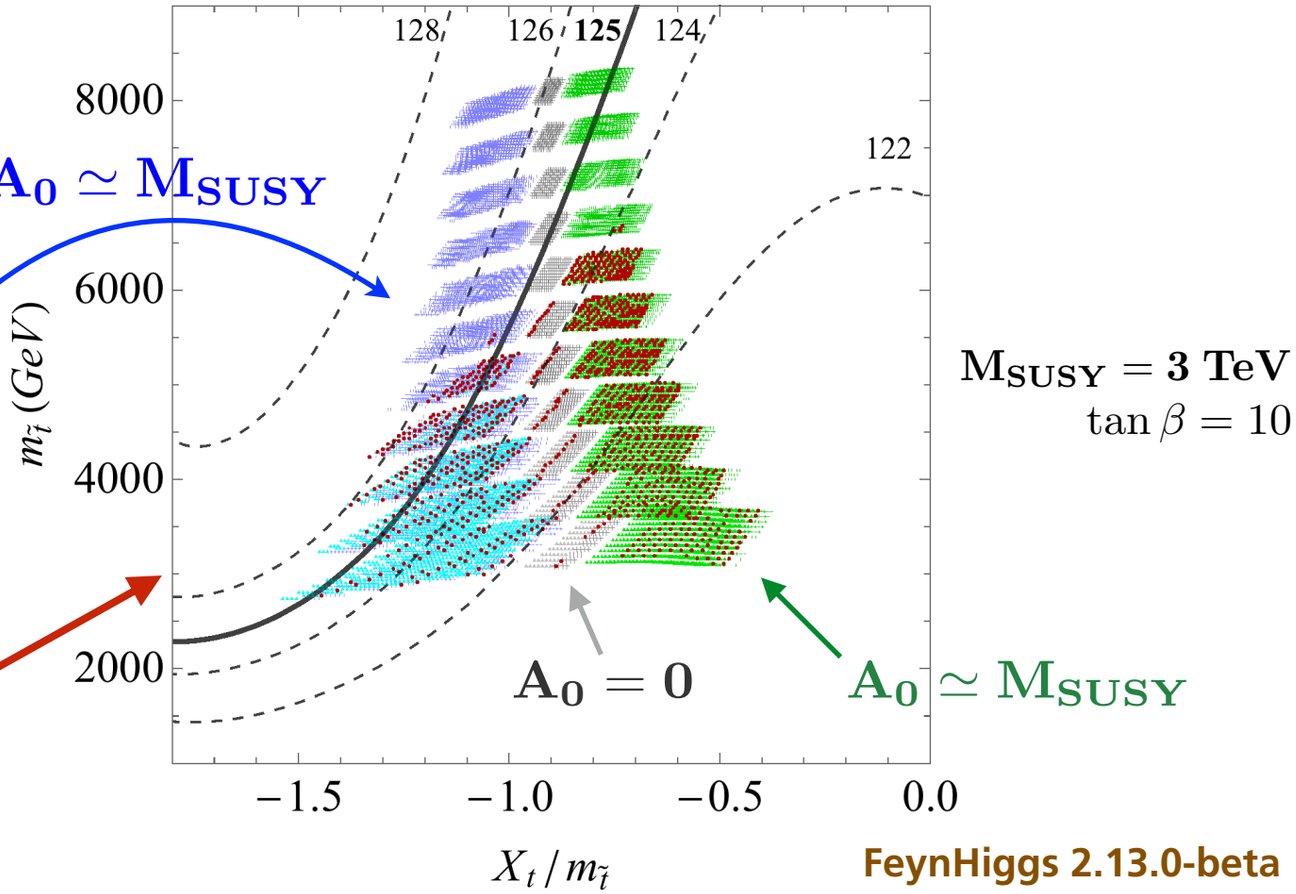
**Prediction for maximal hierarchy is very robust.**

# Minimally specified CMSSM

## Higgs boson mass from minimally specified inputs:




$\mathbf{m_{\tilde{t}} \lesssim 30\, M_Z}$




**Only scenarios with negative A-terms can have sufficiently heavy stops to explain the Higgs boson mass**

# Conclusions

The usual naturalness criteria do not necessarily indicate how model parameters have to be tuned.

**I advocated considering any outcome that does not require specifying more than one digit of model parameters as natural.**

In the CMSSM, up to ~3 TeV superpartners are natural in this sense. Only one digit of model parameters needs to be adjusted to get ~100 GeV electroweak scale, no matter what the remaining digits are. Parameter choices with negative A terms can give the correct Higgs mass.